Division of Compensation Analysis and Support Technical Basis Document: Basis for Development of an Exposure Matrix for Bethlehem Steel Corporation, Lackawanna, New York; Period of Operation: 1949-1952	Document Number: DCAS-TKBS-0003 Effective Date: 11/30/2010 Revision No.: 01 Controlled Copy No.: _____ Page 1 of 34
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RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
Draft	12/17/2002	0-A	New document to establish the technical basis for the development of a radiation exposure matrix for Bethlehem Steel Corporation. Initiated by Jeri L. Anderson.
03/31/2003	03/31/2003	00	First approved issue of ORAUT-TKBS-0001.
06/29/2004	06/29/2004	01	Approved issue of Revision 01.
7/27/2006	7/27/2006	00	Approved issue of Revision 0 of OCAS-TKBS-003. This supersedes rev. 1 of the previous ORAUT-TBKS-0001.
09/16/2010	11/29/2010	01	Revision initiated to incorporate SEC designation information; additional changes include deletion of unnecessary information throughout document affected by SEC; added information regarding recycled uranium at BSC and additional rolling data to Table 1; corrected minor typographical errors; included NIOSH internal comments.

1.0 PURPOSE AND SCOPE

Technical Basis Documents and Site Profile Documents are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH and its contractors in the completion of the individual work required for each dose reconstruction.

This technical basis document (TBD) specifically addresses exposures incurred by workers as a result of a contractual agreement between Bethlehem Steel Corporation (BSC) and the U.S. Department of Energy (DOE) or its predecessors for work to be performed at BSC's Lackawanna Plant (a designated atomic weapons employer (AWE) facility). Dose reconstructors should use the information in this TBD to evaluate the DOE derived occupational radiation dose for workers at Bethlehem Steel. These doses include external and internal radiation sources as well as occupationally required diagnostic x-ray examinations.

In this document the word "facility" is used as a general term for an area, building or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy facility" as defined in the Energy Employee Occupational Illness Compensation Program Act of 2000 (42 U.S.C. § 7384l (5) and (12)).

Employment at an AWE facility is categorized as either (1) during the contract period (*i.e.*, when the AWE was processing or producing material that emitted radiation and was used in the production of an atomic weapon), or (2) during the residual contamination period (*i.e.*, periods that NIOSH has determined there is the potential for significant residual contamination outside of the period in which weapons-related production occurred). For contract period employment, all occupationally-derived radiation exposures at the facility must be included in dose reconstructions. NIOSH does not consider the following exposures to be occupationally-derived:

- radiation from naturally occurring radon present in conventional structures; and
- radiation from diagnostic X-rays received in the treatment of work-related injuries.

For residual contamination period employment, only the radiation exposures defined in 42 U.S.C. § 7384n(c)(4) (*i.e.,* radiation doses received from DOE/AEC-related work) must be included in dose reconstructions. Radiation dose received from DOE/AEC-related work includes: (1) radiation from radon consistent with NIOSH's policies for including such radiation in the contract period; and, (2) medical screening X-rays, but not diagnostic X-rays for the treatment of work-related injuries. It should be noted that: (1) under subparagraph A of § 7384n(c)(4), radiation associated with the Naval Propulsion Program is specifically excluded from the employee's radiation dose; and, (2) under subparagraph B of this section, radiation from a source not covered by subparagraph A that cannot be reliably distinguished from radiation that is covered by subparagraph A is considered part of the employee's radiation dose. This site profile covers only exposures resulting from nuclear weapons-related work. Exposures resulting from non-weapons related work, if applicable, will be covered elsewhere.

The Secretary of Health and Human Services (HHS) has designated a class of employees from the Bethlehem Steel Corporation (BSC) for inclusion in the Special Exposure Cohort (SEC). The approved class consists of all Atomic Weapons Employer employees who worked at the Bethlehem Steel Corporation facility in Lackawanna, New York from January 1, 1949 to December 31, 1952, for a number of work days aggregated at least 250 work days, occurring either solely under this

employment or in combination with work days within the parameters established for one or more other classes of employees in the SEC.

NIOSH has determined, and the Secretary, Health and Human Services has concurred, that it is not feasible to reconstruct radiation doses (both internal and external) from exposures to uranium radionuclides for all Atomic Weapons Employer employees who worked at Bethlehem Steel Corporation prior to 1951. For the period 1951-1952, NIOSH has determined, and the Secretary, Health and Human Services has concurred, that it is not feasible to reconstruct internal radiation doses from internal exposures to uranium radionuclides for Bethlehem Steel Corporation cobble cutting activities. Although NIOSH has found that it is not possible to completely reconstruct radiation doses for the proposed class, NIOSH intends to use any internal and external monitoring data that may become available for an individual claim and that can be interpreted using existing NIOSH dose reconstruction processes or procedures. Therefore, dose reconstructions for individuals employed at Bethlehem Steel Corporation during the period January 1, 1949 through December 31, 1952, but who do not qualify for inclusion in the SEC may be performed using these data as appropriate. Additionally, NIOSH considers the reconstruction of occupational medical exposures to be feasible for members of the class during the covered period of 1949-1952.

Many sources of information were evaluated and utilized in the preparation of this TBD. These include transcripts of worker outreach meetings, worker interviews and comments, multiple reviews by EEIOCPA HHS contractor SC&A, and information gathered at various Department of Energy record repositories including, but not limited to, the Environmental Measurements Laboratory (EML) and Hanford.

This document is divided into 6 sections. These are: 1) Purpose and Scope; (2) Site Description and Operational History; (3) Estimation of Internal Exposure; (4) Estimation of External Exposure; (5) Occupational Medical Dose; and (6) Occupational Environmental Dose.

2.0 SITE DESCRIPTION AND OPERATIONAL HISTORY

2.1 Background of rolling operations conducted by AEC 1948-1952

Bethlehem Steel Corporation was one of several steel mills that contributed to the production of uranium metal rods used by Hanford for the production of plutonium. The principal means of producing uranium rods during World War II was an extrusion process conducted at Hanford. Rolling of uranium metal rods was investigated at Joslyn Manufacturing and Supply Co. during and after the war effort to evaluate methods to improve product quality and reduce losses of product during the manufacturing process. Another development that promised improvements in the production of uranium metal rods was the successful rolling of lead dipped uranium billets by Joslyn in 1948, which, according to the early AEC reports, were far superior to the Hanford materials in terms of blistering. Hanford stopped extruding uranium rods in 1948. Rolled uranium rods manufactured offsite of Hanford were found to be a less expensive process and possessed metallurgical advantages over the extrusion process (DOE 1997).

As of 1947, postwar production of uranium was transferred to the US Atomic Energy Commission (AEC) New York Operations Office (NYOO). Safety aspects of these operations fell under the Health and Safety Laboratory (HASL) for the stated reason that many of these facilities were small and lacked the resources for evaluating worker health (AEC 1949b). HASL (later to be renamed the Environmental Measurements Laboratory) had responsibility for these programs until 1954 with the

implementation of parallel production centers in St. Louis and Cincinnati and reorganization of uranium production responsibilities to other offices of the AEC (AEC 1958, p 10).

During the time frame of 1947 to 1954, NYOO had broad responsibility for the procurement and processing of uranium for weapons production. These responsibilities included acquisition of raw ore materials from Africa and other sites; all aspects of its storage; processing of the raw ore; preparation of uranium oxide; conversion to green salt (UF_4); preparation of uranium metal billets; and the rolling of the billets into rods. The uranium metal was delivered as billets to two mills (as of 1949), Simonds Saw and Steel Company, Lockport, New York and Vulcan Crucible Steel Company, Aliquippa, Pennsylvania who rolled the billets into rods which were shipped to Hanford (AEC 1949a, p3). Joslyn Manufacturing and Supply Co. continued to provide additional capacity during start-up of the rollings at Simonds as ~150 tons of uranium per month was needed by Hanford (AEC 1948c, p 128). It is known that other rolling mills also participated in rolling operations during this early time period. Simonds Saw and Steel Co. later became the principal manufacturer of rods as Vulcan was unable to roll the larger billets coming from Mallinckrodt.

During the war, permissible levels for natural uranium dust in air were set at 500 $\mu g/m^3$ for insoluble uranium compounds and 150 $\mu g/m^3$ for soluble compounds. After the war, the University of Rochester lowered its recommendation for soluble uranium compounds to 50 $\mu g/m^3$ on the basis of chemical toxicity, which is equivalent to 70 disintegrations per minute per cubic meter (alpha activity of ^{234}U and ^{238}U). The University based this level primarily on animal studies. The Medical Division of the New York Operations Office felt that a "maximum permissible level" was really unknown and should be based on human data. Therefore, 50 $\mu g/m^3$ level was referred to as the "preferred level" (AEC 1949b). Many AEC contractors used the term Maximum Allowable (air) Concentration (MAC) interchangeably with "preferred level" and often reported air-sampling results as multiples of the MAC (NLO 1952b; AEC 1953). As of 1949, NYOO did not recommend the use of respirators (AEC 1949a).

Several operations conducted as part of the uranium processing at Bethlehem Steel are important to have a conceptual understanding of their impact on exposure during the activities conducted at the Lackawanna Plant. These include:

Furnace heating: In some cases uranium was preheated in the furnace and then further heat treated in a lead or salt bath.

Lead bath heating: Similar in nature to the furnace heating, uranium rods and billets were immersed in a molten lead bath to heat them to the desired temperature for rolling. The lead also served to provide a partial coating for reduction of uranium dust during the operations.

Salt bath heating: Similar in nature to the furnace heating, a molten salt bath was used to heat the uranium rods and billets prior to rolling. This salt also provided a protective covering which significantly reduced the uranium oxide formation and airborne contamination levels during rolling.

Centerless grinding: The canning process required a precision ground uranium piece. HW-19066 describes the process of centerless grinding using a No. 3 Cincinnati Centerless Grinder using initial (rough) pass removing 0.005"-0.010" with finishing passes removing 0.001"-0.002". The basic principle was for the cutting pressure of the grinding wheel to keep the rod in contact with the rest blade and the regulating wheel. The rotation of the regulating wheel causes the rod to rotate at a constant peripheral speed and the inclination of the regulating wheel axis moves the work from the front to the rear of the machine. The operation of grinding uranium required the use of a constant flow of coolant.

Hand grinding: Some reports indicate that grinding of the rods was a component of the work performed by the Lackawanna facility. Other facilities indicated the need to perform both centerless grinding and hand grinding of materials. Hand grinding may have been used to remove surface imperfections prior to rolling as well as cleanup of the slugs after they were sheared into 4" and 8" pieces. Since the product sent to Hanford included both rods and slugs, hand grinding was considered as a potential exposure source and data at Joslyn was evaluated to compare the source term with the assigned intake levels.

Medart straightening: Uranium rods and in some cases slugs were straightened. In some cases this was done prior to centerless grinding, in others simply to improve the product straightness prior to shipment to Hanford where final machining was undertaken.

Billet: Large cylinder of uranium metal up to 5" in diameter and up to 2 feet in length weighing between 125 to 500 pounds.

Rod: Uranium billets were rough rolled and then finished rolled into long, thin rods. The rods were often the final product shipped to Hanford.

Slug: Uranium rods were cut into 4" and 8" pieces called slugs (sometimes at Hanford, sometimes at a facility offsite to Hanford) which were dipped and canned for use in the reactors.

2.2 Bethlehem Steel Corporation

Bethlehem Steel Corporation was one of the largest steel manufacturers in US history, with an annual output of material after World War II that exceeded twice the output of the entire country of Germany at that time (Leary 1987). Bethlehem Steel acquired the Lackawanna facility in 1922. While Bethlehem Steel had widespread holdings in ship building and other interests, only the facilities located in Lackawanna, NY are the subject of this TBD. Diagrams of the site are available (Leary 1987) to provide a reference to the scale of this 1300 acre complex which employed approximately 20,000 workers during this time period.

The U.S. Atomic Energy Commission (AEC) contracted with Bethlehem Steel Corporation (BSC) to develop improved rolling mill pass schedules using a continuous rolling mill. These rollings were tied strongly to the design of the Fernald facility which was to be based on a continuous rolling mill technology such as that used at BSC whose design was to be developed by Birdsboro Corporation (Summary 1951). Many documents associated with the development of the uranium rolling program and its progress have been obtained by NIOSH and its contractors and may be referenced for additional detail including, but not limited to HW-13168, HAN-21441, HAN-30471, HAN-30686, HAN-30987, HAN-31429, HW-14816, HW-20548, GEH-17116, HAN-20104, HW-24222, HW-20548, HW-22474, HW-22878, and a series of unnumbered Bethlehem Steel memos obtained from Hanford which are contained in the NIOSH Site Research Database (SRDB).

Programmatic goals associated with these rollings were (HW-24849):

- To evaluate the continuous rolling mill using a source of uranium rods for the plutonium production program at Hanford and Savannah River;
- Information gained during these rollings would be used for the design of the Fernald plant;

- Evaluate technological improvements leading to reduced oxidation of uranium metal by the use of lead bath and salt bath heating (using a combination of lithium and potassium carbonate salts) would reduce losses during rolling; and,

- Evaluate the metallurgical implications of heat treatments to improve quality during irradiations.

Review of the historical records show that BSC conducted this work under the oversight of HASL, Hanford Works, and National Lead of Ohio (DOE 1985). Records indicate that BSC participated in both experimental and production runs. The purpose of this program included the following:

- Finish rolling of bars rough rolled at Simonds Saw or Aliquippa Forge (Summary 1951);

- Comparison of lead bath and salt bath heating on product and process quality;

- Heat treating rods and billets rolled or to be rolled at other facilities which in some cases also included grinding as part of this preparation; and,

- Production runs of uranium rods from rough rolled rods.

The uranium billets were prepared by Mallinckrodt Chemical in St. Louis, Missouri, shipped to the rough rolling mill and then shipped to Lackawanna in freight cars. The freight cars, which were spotted at the BSC plant, served as storage for the uranium billets during the week (Range 1976; ORNL 1980; DOE 1985). The rolling experiments generally took place on weekends because the mills were in full use 5 days per week. The work only involved the 10-in. bar mill and associated billet preparation and handling equipment (LaMastra 1976; Range 1976; Thornton 1977; ORNL 1980; DOE 1985). Review of Hanford documents also shows that some activities involved only the heat treatment of metal rods and billets in the salt bath to get the proper grain structure in the metal preferred for irradiation of the material at Hanford. These grain structures, known as the alpha, beta and gamma phases, describe the metallurgical properties of the material and are not associated with radioactivity in this context.

According to some accounts, material accountability practices for the project included collection of scale, residue, fine debris, and cropped ends. Worker accounts (6-19-2006) reported the use of vacuum cleaners to assist in the cleanup in many areas. These materials were packaged, and returned to the AEC which had a documented scrap recovery program (LaMastra 1976; Range 1976; ORNL 1980; DOE 1985). Radiological surveys in 1976 and 1980 of the original facility and equipment, which were still in existence, identified no residual contamination above natural background levels (LaMastra 1976; ORNL 1980; DOE 1985).

A number of documents provide conflicting information regarding the time period during which the rollings occurred. Some references indicate that all work occurred between 1949 and 1951 (Summary 1951; LaMastra 1976; ORNL 1980). However, other reports indicate that eight additional rollings occurred in 1952 (Bowman et al. 1952; Hershman 1952; NLO 1952a; DOE 1985), although they were reported to be production rollings. A letter from a labor representative in October 1979 asserted that six to eight rollings took place in 1955 although no verification of these dates has been found (Kosanovich 1979, 2004). The work was transferred to the Fernald Plant around September 1952 as it began pilot and then full scale operations (NLO 1952a; LaMastra 1976; Range 1976). Information obtained from the rolling experiments at BSC was used in the design of a rolling mill at the National Lead Company plant in Fernald, Ohio, which began production in 1953 (LaMastra 1976; Range 1976). Table 1 lists the dates of rollings at BSC for which documentation has been found.

Several documents report that AEC personnel were present during all rolling operations and several site visit reports have been obtained that document these visits. AEC personnel conducted air and surface radioactivity monitoring and checked personnel involved in the rolling for contamination during some of these rollings (LaMastra 1976; ORNL 1980; DOE 1985). Some reports indicate that no records are available of these monitoring activities (LaMastra 1976; Range 1976; ORNL 1980). As of 1976, it was believed that if monitoring records ever existed, they were not retained (LaMastra 1976). Uranium metal accountability records apparently were destroyed (Range 1976). Review of AEC historical records, however, has produced several documents containing air sampling data from the Health and Safety Laboratory (HASL) and National Lead Company for the rollings shown in Table 1. Many documents were available from the Hanford archives because the work was associated with improvements to the irradiation of uranium fuel for plutonium production.

While the operations involving the processing of uranium were limited to the 10" continuous rolling mill and associated handling facilities (Figures 1 and 2), the time lapse and complexity of the site make clear evaluation of exposure potential by job title difficult. The 10" continuous rolling mill and associated localized bar material handling facilities were completed in 1947 with monthly capacity measured in thousands of tons of steel per month. The process was also known to create widespread contamination within the mill area during the processing of the uranium. Therefore all workers at Bethlehem Steel in Lackawanna will be evaluated as having a potential for internal and external exposure as if they worked in the rolling mill during these operations. These evaluations are explained in the following sections.

Figure 1: 10-inch bar mill at Lackawanna circa 1950 (Walker 2005)

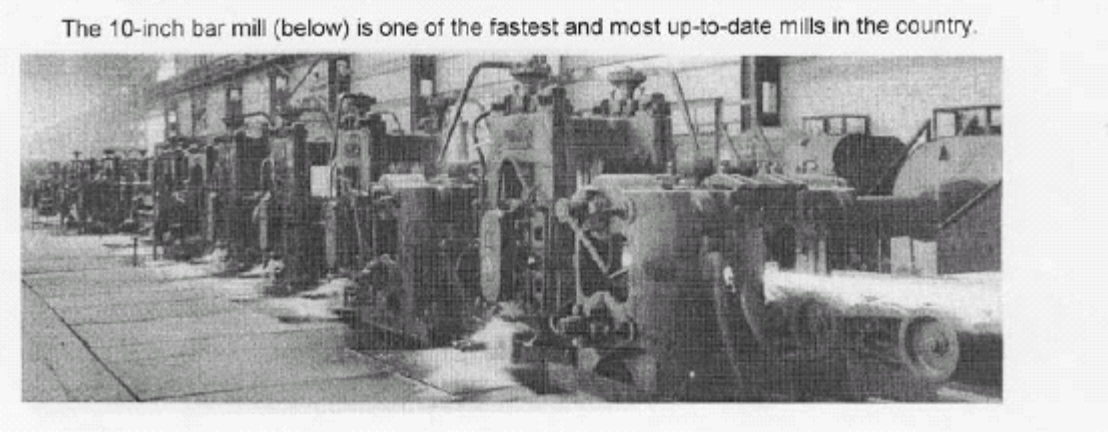


Figure 2: Lackawanna continuous stand rolling mill diagram as provided by a retired employee and drafted by SC&A (SC&A 2005).

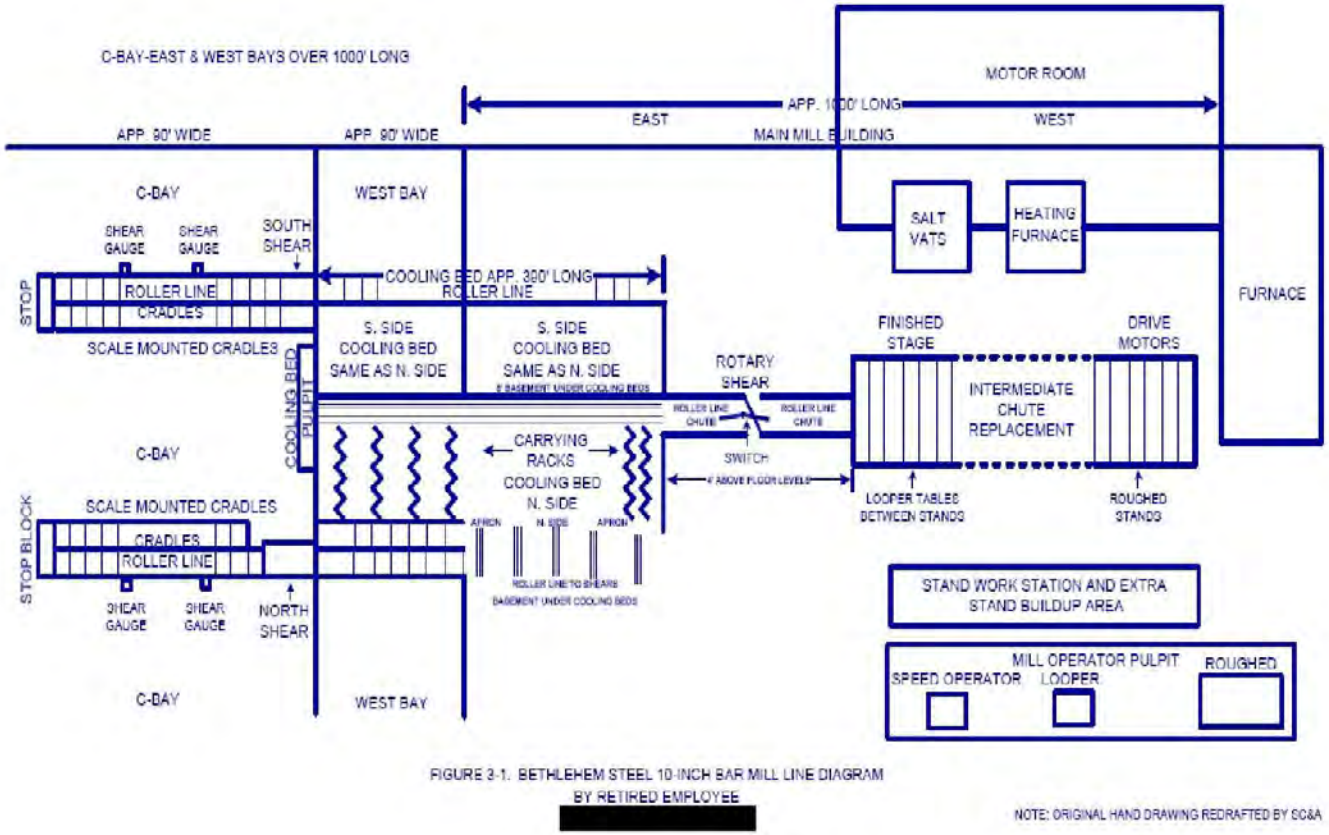


FIGURE 3-1. BETHLEHEM STEEL 10 INCH BAR MILL LINE DIAGRAM
BY RETIRED EMPLOYEE [redacted]

NOTE: ORIGINAL HAND DRAWING REDRAFTED BY SC&A

Table 1: Documented rollings at Bethlehem Steel Corporation, Lackawanna, New York

Date	Day	Type or designation	Billets rolled	Bath type	Air Sample Data	Reference
April 26-27, 1951	Thurs., Fri.	Experimental #1	26	Lead/salt	Y	Summary 1951 AEC 1951b Sheets 6191, and 6192
July 29, 1951	Sunday	Experimental #2	24	Lead/salt	Y	Summary 1951 Sample sheets 6425, 6436, 6437
August 27, 1951	Sunday	Experimental #3	32	Lead/salt		Summary 1951 HW-22347
September 30, 1951	Sunday	Experimental #4	43	Salt	Y	Sample sheet 6539 HW 23910
October 28, 1951	Sunday	Lackawanna #5	93	Salt	Y	HW-22975 Sample sheets 6532, 6533
January 26-27, 1952	Saturday, Sunday	Production	25 plus 4 tons heat treated only	Salt	Y	AEC 1952b HW-23399 HW-24849, HW-23269 Sample sheets 6543, 6544, 6545
February 16, 1952	Saturday	Production	120 30 tons	Salt		HW 23697
March 15, 1952	Saturday	Production	218	Salt	Y	NLO 1952b Sample sheets 6573, 6574
April 12, 1952	Saturday	Production	222	Salt		NLO 1952a
May 10-11, 1952	Saturday, Sunday	Production	461	Salt		FMPC-26
August 17, 1952	Sunday	Production	157	Salt		Bowman 1952
August 31, 1952	Sunday	Production	219	Salt		Bowman 1952
September 14, 1952	Sunday	Production	303	Salt	Y	Schneider Sample sheet IH33, IH34, IH35, IH36
September 22, 1952	Monday	Production	302	Salt		Schneider
October 20, 1952	Monday	Production	359	Salt		FMPC-84
October 25, 1952	Saturday	Production	237	Salt		FMPC-84

1951: Six rolling days, plus assume one January, February, March, May, June, November, December (13 rollings). There was no Experiment #6 at Lackawanna (cancelled after rough rolling).
1952: 10 rolling days, plus assume one for May, June, July, November, December (15 rollings)

3.0 ESTIMATION OF INTERNAL EXPOSURE

3.1 Health and Safety Laboratory Air Monitoring Program

The production of rods by US industrial facilities had been intended to be of short duration to support the war effort, however, it became apparent to NYOO in 1949 that these resources would be used for an indefinite period (AEC 1949b, p5). Concerns mounted over known exposures to radioactive materials which exceeded even war year standards promulgated by the University of Rochester. These levels were much higher than standards being proposed and which were eventually adopted. HASL implemented a program of air sampling at many of these facilities to evaluate and reduce the exposures to workers. These programs and mitigating ventilation plans for these facilities were discussed in the May 1948 NYOO monthly report (AEC 1948c, p140).

From the early days of operation, the Health and Safety Laboratory (HASL) of the Atomic Energy Commission (AEC) relied on time weighted average exposure measurements to assess inhalation hazards in the workplace. A brief description of the HASL methodology, and its relation to ICRP 75, is provided below.

A detailed description of the HASL methods and background on air monitoring and exposure assessment was provided in a 1973 write-up in the HASL manual (chapter B-04, The Application of Air Sampling in the Evaluation and Control of the Occupational Environment, AEC 1973). The detailed description of the concept of representative workplace monitoring was written by A.J. Breslin, Director, Health Protection Engineering Division, HASL. It should be noted that Mr. Breslin was one of the sample collection scientists for the Bethlehem Steel Corp uranium dust monitoring data. Breslin's write-up provides a detailed discussion of the type of samples taken, how they were taken, how they were analyzed, and how the results should be interpreted. The discussion of sampling locations, designation of sampling sites and the job task analysis sheets contained in this document are consistent with the sampling strategy employed at both Simonds Saw and Steel (SSS) and Bethlehem Steel Corporation (BSC). Early HASL procedure manuals were primarily focused on the chemistry, so earlier versions of the text may not exist (personal communication, Dr. Isabelle Fisenne). The following text, excerpted from the HASL manual, provides a description of the various sample types that were used by HASL to evaluate representative exposure.

> ***Breathing Zone Samples****- Typically, a worker performs a few operations in which he may come into close or direct contact with the hazardous material. Examples of these operations are operating a machine tool, charging a furnace, working at a chemical hood, changing the glove on a dry box, or any one of a hundred maintenance tasks that involve the dismantling of or entrance to equipment. At jobs such as these, dust concentrations are apt to be much greater than in the general area. Therefore, these activities may influence the average exposure far out of proportion to their duration.*
>
> *To measure accurately the concentration to which a worker is exposed while performing such a task, a breathing zone (BZ) sample must be collected. The sampling instrument is held in the vicinity of the worker's breathing area for the duration of the task. It should be held as close to his nose as possible short of interfering with his freedom of movement, because in situations where dust is escaping from a small aperture, concentration gradients around a source can be sharp. In one uranium plant, samples collected one foot apart at certain operations have shown concentration differences of twenty-fold. On the other hand, a sample collected so close as to interfere with the worker's movements is invalid because the job cannot be*

performed in the normal fashion. A small deviation in work habit may alter the dust concentration markedly.

***General Air Samples**- Usually, the total time spent by a worker on operations requiring BZ samples constitutes a small fraction of the day. There are, of course, exceptions… Worker exposure during the balance of the work day may be characterized by samples collected of the general air (GA) in the area that he occupies.*

A GA samples is one that is collected at a fixed location during a sustained sampling period. To be meaningful, the sample must be collected within an occupied area but also it must be away from dust sources except those that may dominate the area. Customarily, the sampling instrument is placed at a height from four to six feet from the floor although in a heavily trafficked area, the instrument must be placed over the heads of the workers to avoid interference with the normal work routine….

***Process Samples**- There is yet another kind of air sample that is often useful, the process sample. It is used to identify sources of air contamination or to determine the relative strengths of two or more sources. Process samples are distinguished from BZ and GA samples by the fact that they are taken in and around process equipment at locations where employees normally are not exposed. For this reason they should never be used in the evaluation of occupational exposure.*

As an example, a process sample might be collected directly over a furnace to determine the amount of radioactivity that is carried by convection from the furnace to the room. The concentration at that point is not representative of an employee's exposure.

These sampling methods meet the most current recommendations from ICRP Publication 75 (ICRP 1997) regarding the collection of representative samples for the purpose of determination of exposure. As indicated in the excerpts below from the HASL procedures manual, the BZ samples collected by HASL were held in a position to represent the breathing zone and are not associated with a fixed sampler. Because of this, the ICRP 75 recommendation that samples collected from area samplers be corrected to breathing zone would not be appropriate for these samples. General area (GA) samples were taken with the expressed purpose of evaluating non-localized releases to which an employee could be exposed during the course of the day. Finally, process samples (P) that were obtained during the measurement period were to assess source terms and are not indicative of concentrations to which workers may have been exposed. Further evidence of the breathing zone sampling location comes from typical operations at National Lead which states, "BZ (breathing zone) samples were collected by holding the sampling device in the immediate vicinity of the worker's head, in front of the shoulder area."

Samples were collected on 1 1/8" disks of Whatman #41 filter paper which provide high efficiency collection of particles in the particle size range. These filters have a maximum flow rate of about 20 L/min (0.020 m^3/min). The procedure for the collection of samples at Simonds Saw and Steel on October 27, 1948 is discussed by the HASL representative in the report (AEC 1948a). Further discussion of the counting methods employed by the HASL is contained in the procedure "Determination of Uranium in Air Dust Samples by Alpha Counting Methods" (AEC 1949c) and by direct account of one of the HASL laboratory employees (personal communication, Dr. Naomi Harley, 2004). While the current standards for documentation of calibration of the counting and sampling equipment have changed significantly since the early days of industrial hygiene, the relative contribution to uncertainty in the measured air concentration associated with these factors is very

small compared to the large changes in air concentration as a function of time and location. While this TBD does not use time weighted averages to determine exposure to uranium dust, HASL reported very good agreement in comparing time weighted averages of exposure with results obtained from personal lapel-mounted air samplers after they became available in the late 1960s (Breslin 1967). This agreement provides additional support for the reliability of the data and the use of time-weighted average air sample results to estimate exposure.

3.2 Recycled Uranium at Bethlehem Steel

Until 1952, all uranium used by the AEC was derived from natural sources because processes that recover uranium from spent fuel were not available. Plutonium was extracted using a $BiPO_4$ process in the T-plant and B-plant at Hanford. This process did not extract uranium from the spent fuel. The uranium and the remaining waste products were collected in waste storage tanks (DOE 2000).

In 1952, the Hanford plant began using the REDOX process to extract plutonium from spent fuel. The REDOX process was also capable of extracting uranium from the spent fuel for reuse. The uranyl nitrate (UNH) output of the REDOX plant was converted to UO_3 at the UO_3 plant (224-U building) at Hanford. Along with the UO_3 plant, the U-plant began operating in 1952. This plant was used to extract the uranium from the previously collected waste. The plant produced UNH which was then sent to the UO_3 plant to produce UO_3 (DOE 2000).

The UO_3 plant began operating in January 1952 with cold (non-recycled) uranium to test the plant. The first shipment of recycled uranium was on March 10, 1952 to the K-25 plant. At K-25, the UO_3 was to be converted to UF_6 for feed to the cascades; however, impurities in the UO_3 from the UO_3 plant caused difficulties in the conversion process. As a result, UO_3 from Hanford was diverted to Harshaw where it was to be purified before going to K-25. Later improvements in the REDOX and UO_3 conversion process eliminated the need for this step (DOE 2000).

Through June 30, 1953, all shipments of recycled uranium from Hanford went to either K-25 or Harshaw (DOE 2003). While in the past, Harshaw had produced various chemical compounds of uranium, by July 1952 only UO_3 was being produced and it was all being supplied to K-25 (ORAUT 2009). K-25 did not admit any recycled uranium to the cascades until fiscal year 1953 (July 1, 1952 to June 30, 1953) (DOE 2003). Much of the recycled uranium at K-25 was sent to Paducah (DOE 2003). Paducah was just finishing initial construction in 1952. The first withdrawal of product from the cascades at Paducah occurred in November of 1952 but recycled uranium was first fed to the cascades in July 1953 (ORAUT 2007).

Until the mid 1950s, reactors at Hanford and Savannah River were fueled with uranium that originated from natural ores. All the recycled uranium up to that point was sent to enrichment plants either directly or indirectly. Enriched uranium from the enrichment plants was used in nuclear weapons and for other purposes but not to fuel plutonium production reactors. The plutonium reactors' fuel chain at that time was then, ore to metal to reactor to plutonium/uranium separation to enrichment plant to weapons. The irradiated uranium was not reused to make reactor fuel and so the reactor fuel system was a chain rather than a cycle. In the mid 1950s, plutonium reactors began using enriched uranium fuel. Later, they used enriched uranium fuel with depleted uranium target material. Once enriched or depleted uranium use began at the plutonium reactors, recycled uranium would have been used in the fuel manufacturing plants and the fuel system because a cycle rather than a chain.

Therefore, recycled uranium was not introduced to the production reactor fuel plants until the mid 1950s. The uranium rolled at Bethlehem Steel was part of the reactor fuel chain, initially testing only and later producing some of the uranium rods for the Savannah River reactors. Since the last

documented rolling of uranium at Bethlehem Steel was October 25, 1952, recycled uranium is not considered to have been present at Bethlehem Steel.

3.3 Parameters affecting intake estimates and uncertainty at Bethlehem Steel

As previously discussed, NIOSH has determined, and the Secretary, Health and Human Services has concurred, that it is not feasible to reconstruct internal radiation from exposures to uranium radionuclides for all Atomic Weapons Employer employees who worked at Bethlehem Steel Corporation from January 1, 1949 – December 31, 1950. For the period 1951-1952, NIOSH has determined, and the Secretary, Health and Human Services has concurred, that it is not feasible to reconstruct internal radiation doses from internal exposures to uranium radionuclides for Bethlehem Steel Corporation cobble cutting activities. Although NIOSH has found that it is not possible to completely reconstruct radiation doses for the proposed class, NIOSH intends to use any internal monitoring data that may become available for an individual claim and that can be interpreted using existing NIOSH dose reconstruction processes or procedures. Therefore, dose reconstructions for individuals employed at Bethlehem Steel Corporation during the period January 1, 1949 through December 31, 1952, but who do not qualify for inclusion in the SEC may be performed using these data as appropriate.

A number of parameters must be specified in order to determine radiation dose from inhalation and ingestion of uranium (e.g., breathing rate) and associated uncertainty with these estimates. The recommended default values from the ICRP in Publication 66, *Human Respiratory Tract Model for Radiological Protection,* shall be used unless otherwise specified. The following discussion addresses the parameters to be used for the reconstruction of internal dose at the Lackawanna, NY facility.

3.3.1 Breathing Rate

ICRP 66 provides for two distinct types of workers, *light workers* and *heavy workers*. Both represent a composite of various levels of exercise. These composites represent an average breathing rate of 1.2 m^3/hr for light workers and 1.7 m^3/hr for heavy workers. This document will assume a classification of all workers at BSC as heavy workers with a breathing rate of 1.7 m^3/hr as a claimant favorable assumption using standard nasal augmenter breathing pattern.

3.3.2 Exposure Duration

In order to determine the total amount of uranium inhaled it is necessary to multiply the airborne concentration by the breathing rate and the time the individual is exposed to that concentration. This gets even more complicated when it is realized that not only does the air concentration vary by location, but also by time. Also, many individuals will move about from location to location throughout the day including break rooms, bathrooms, lunch rooms, etc. HASL recognized this need and developed the methods to determine a time weighted exposure. Such a study was conducted at Simonds Saw and Steel. The individual tasks were timed at various locations, and these exposure times were combined with the air concentrations in the locations to obtain a time-weighted average air concentration. However, no such estimate was conducted at Bethlehem Steel.

Without a time motion study of various tasks, it is necessary to develop a claimant favorable approach to determine the appropriate exposure location and duration. For lack of better information, each individual will be assumed to be exposed for the purposes of internal dose estimation, 100% of the time for each 10 hour day of uranium rolling. This value will be treated as a constant for purposes of

uncertainty analysis to be discussed later. Further discussion of exposure time with respect to internal dose from residual contamination will be discussed later in this document.

Reports from 1951 and 1952 indicate that, with the exception of the April 1951 (Summary 1951), January 1952 (HW-23399), February 1952 (HW-24849), August 1952 (Bowman et al. 1952), September 1952 (Schneider and Yocce undated) and October 1952 rollings, activity occurred on only one weekend day per month. For 1951, an additional 10 hours was added to account for the additional weekday in April, resulting in thirteen 10-hour workdays. For 1952, in addition to the ten documented rollings days, it was assumed that one rolling each took place in May, and June, July, November and December resulting in fifteen 10-hour workdays. Assumptions of 10 hour work rolling days are very claimant favorable estimates based on review of documented rollings which occurred at Lackawanna. For estimates of non-rolling day exposure to residual contamination, 50 weeks of five 10 hour work days minus the number of rolling days were used. Residual contamination is discussed in greater detail later in this document. All partial months shall be treated as full months of exposure.

3.3.3 Exposure Location

As mentioned previously in this document, the exposure location can be difficult to determine. This estimate accounts for location uncertainty by assuming everyone was exposed in an occupation equivalent to the 95th percentile of the area air concentration distribution or other bounding estimates of intake which is explained later in this document.

3.3.4 Absorption Type

The dose derived from inhaling radioactive material depends on the solubility of the material inhaled. The solubility is a parameter describing the rate at which the material is absorbed from the lungs into the bloodstream. The most likely form of airborne uranium at Bethlehem Steel is various uranium oxides. These oxides tend to be absorbed at rates that are between type M and type S parameters described in ICRP 66. The absorption type will affect the dose of organs; however, no one type is favorable to all organs. Type S (very insoluble) will cause higher doses to the respiratory tract than type M but lower doses to systemic organs. Therefore, since the true absorption likely falls between type M and type S, the most favorable solubility type for the case at hand will be used.

3.4 Inhalation Exposure Dosimetry at Lackawanna

3.4.1 Method of analysis

The air sample data from Bethlehem Steel originally consisted of a total of 191 legible air sample results and 13 illegible results drawn and analyzed by the HASL. These samples were collected on various days of rolling in 1951 and 1952. Original records were reviewed by NIOSH and its Advisory Board to determine some of the values because of the poor quality of some of the copies of onion skin type records. The final data set used for the analyses below consisted of 204 total samples with only 1 sample being considered illegible and thus not used. Additionally, 5 samples were quality control samples and were excluded from the analysis of air concentration.

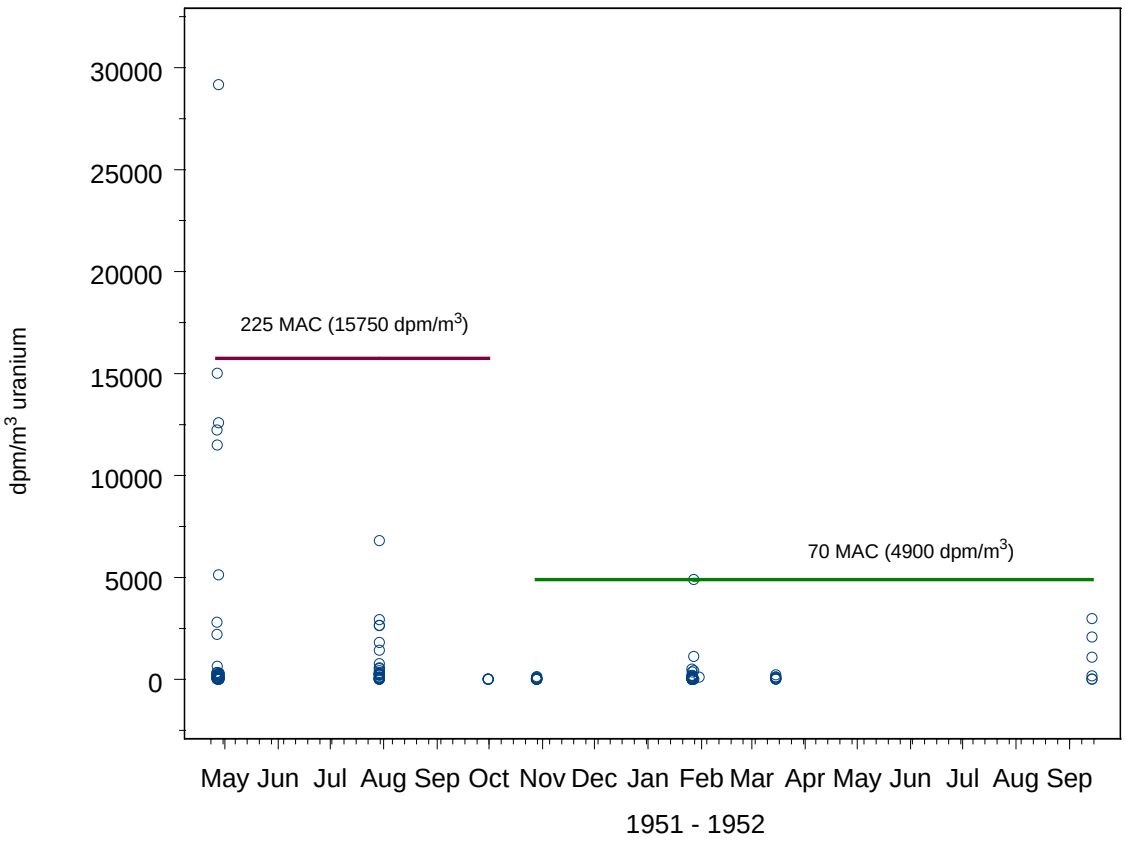
The samples were divided into time periods based on the technology being employed (lead bath or salt bath heating). The following general methods were applied for the analysis of all time periods with specific information being further discussed in individual sections. All valid results, including process samples, were sorted, log transformed, and plotted on a probability plot. The plot contained the z-score (number of standard deviations from the mean) on the X axis and the log transformed data on the Y axis. This allows for a linear regression to be performed on the data to determine the

best fitting straight line. This technique provides a goodness of fit value (utilizing the R squared parameter) as well as an equation for the straight line. The slope of the line then is equal to the log of the Geometric Standard Deviation (GSD) and the Y intercept is equal to the log of the Geometric Mean (GM).

Data from the 1951-1952 time period was divided into two periods to reflect changes that occurred in the processing technologies (e.g., the change from lead bath and salt bath heating to only using salt bath heating). These analyses are explained in detail below. Figure 3 provides a graphical presentation of all the measured air monitoring data at Bethlehem Steel which further validates the need to split the period.

The significant reduction in exposure levels during the later period (October 1951 thru December 1952) created a situation where source terms other than the rolling operation may have been the limiting air concentration. It was determined that the grinding operations provided the highest exposure estimates as explained in the following section. In summary, there are two periods used for evaluation of internal dose: (1) January 1951-September, 1951; and (2) October 1951-December 1952.

Figure 3: Plot of all air monitoring results for natural uranium from Bethlehem Steel.



3.4.2 Evaluation of inhalation exposure for the 1949-1950 time period

NIOSH has determined, and the Secretary, Health and Human Services has concurred, that it is not feasible to reconstruct internal radiation from exposures to uranium radionclides for all Atomic Weapons Employer employees who worked at Bethlehem Steel Corporation from January 1, 1949 – December 31, 1950.

3.4.3 Determination of inhalation exposure for the early 1951 time period

As previously discussed, the air sample data from Bethlehem Steel consists of a total of 204 air sample results, drawn and analyzed by the Health and Safety Laboratory and National Lead. Personnel from National Lead, who conducted the last analysis, were originally from HASL and used the same approaches and time weighted averages. These samples were collected on various days of rolling in 1951 and 1952. Sample types included general area, breathing zone, and process samples. Of the 204 samples, one sample was illegible (after reviewing the original records) and 5 were quality control samples which were not used for these analyses.

Evaluation of the data shows that changes in the process methods clearly impacted the air concentration data which was reflected in the monthly HASL reports and also reports by Hanford personnel participating in the development. An early period from January 1951 to September 1951 was identified in which lead and salt bath technologies were both being evaluated at Bethlehem Steel. It was further recognized that the number of breathing zone samples was a much lower fraction of the total as compared to the Simonds Saw and Steel measurements. For this reason, a breathing zone sample surrogate (BZ-GA) was developed by evaluating the breathing zone to general air sample concentrations at Simonds Saw and Steel and applying this factor to the general air samples during this early 1951 period. Data analysis for this time period was then conducted using the same methods as previously discussed. Figure 4 shows a graphical analysis of data from this time period prior to augmentation. Figure 5 shows the analysis of the augmented data set (includes BZ-GA samples). The 225 MAC (15750 dpm m^{-3}) air concentration represents the 95% level which shall be used for analysis of uranium air concentration during rollings days for this early 1951 period.

Previous sections in this TBD discuss the role that the BSC Lackawanna rolling mill played in the development of continuous rolling experiments for Hanford and also for the comparison of lead and salt bath heating. Only the first four experimental runs conducted in 1951 were known to have used the lead bath heating. Air sampling was conducted on three of those experiments. While it is known that the salt produced a more effective coating for reducing oxidation hence uranium dust, the data has been evaluated together for determination of the 95% air concentration data.

Figure 4: Graph of the distribution and fit of uranium dust concentration data, prior to augmentation with BZ-GA samples, taken at Bethlehem Steel from January 1951 - September 1951 for only those samples obtained for the time (MAC=70 dpm m^{-3}).

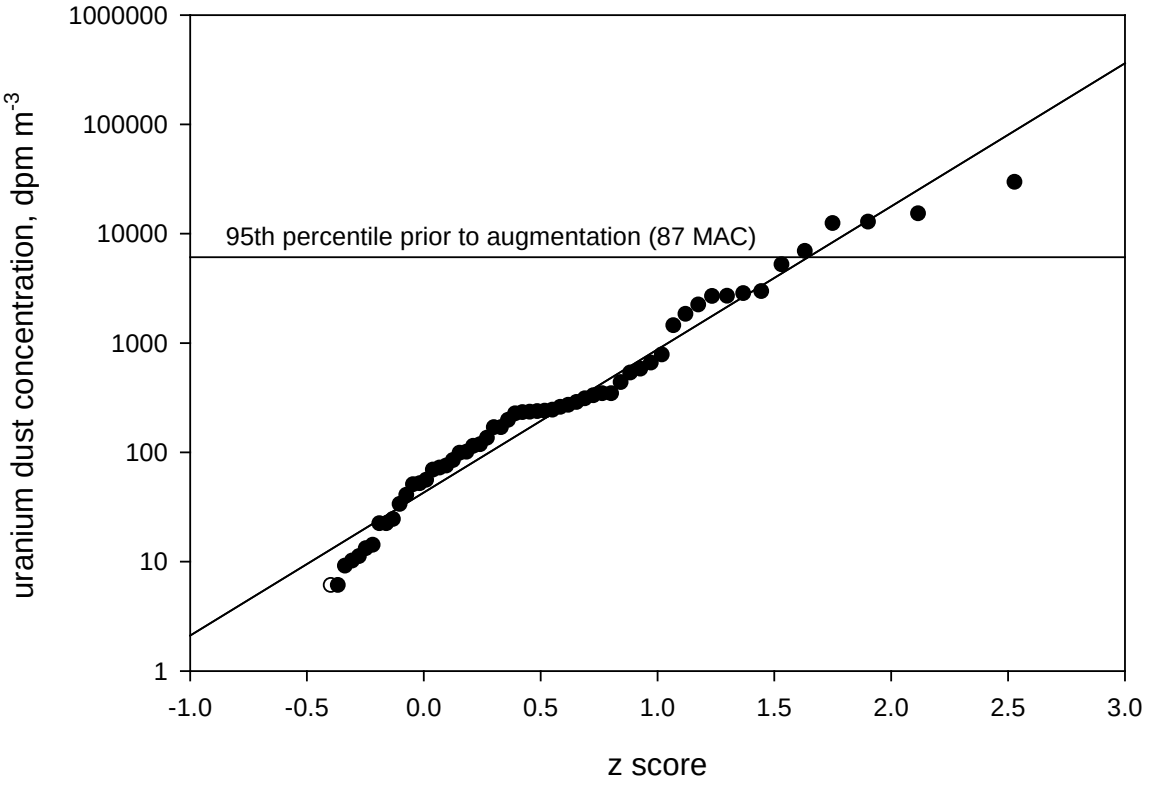
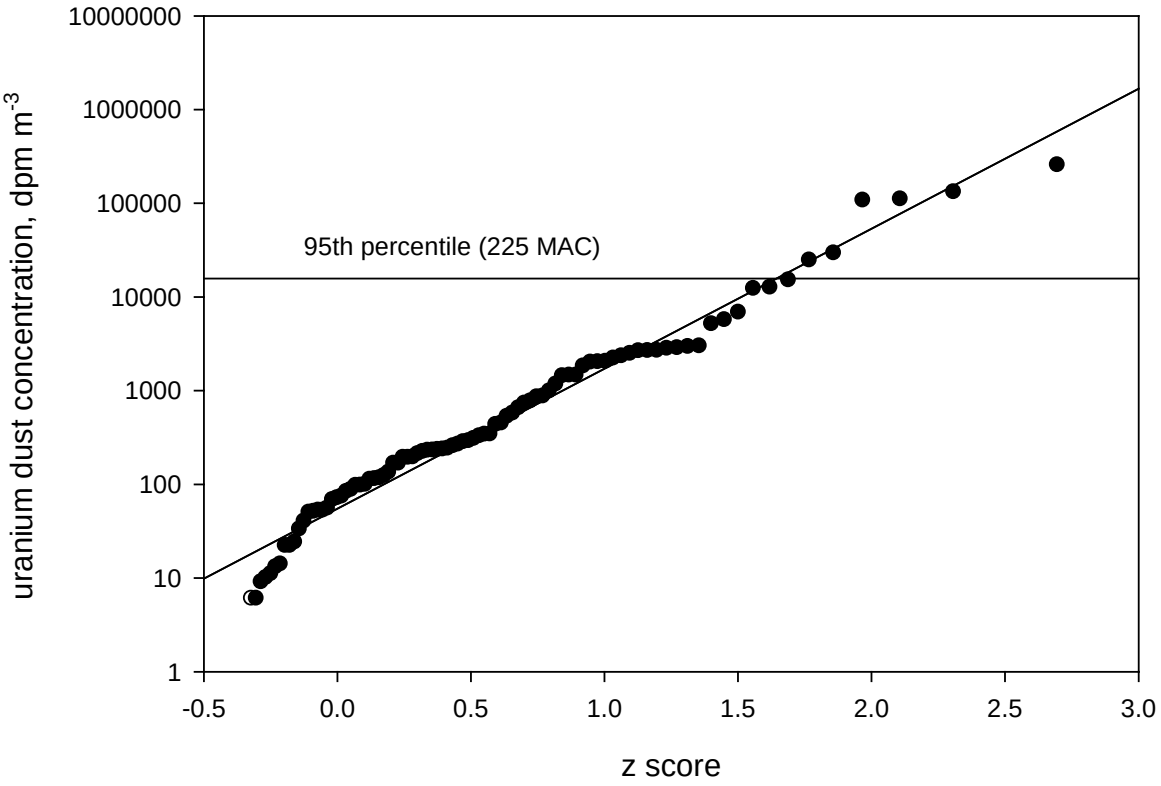


Figure 5: Graph of the distribution and fit of uranium dust concentration data taken at Bethlehem Steel from January 1951 - September 1951 augmented to include BZ-GA samples (MAC=70 dpm m^{-3}). 225 MAC (1575 dpm m^{-3}) is the air concentration level to be used for the assessment of rolling day intakes for this period.



3.4.4 Determination of Inhalation Exposure for the late 1951 - 1952 time period

The majority of uranium airborne contamination in the early period at Bethlehem Steel was caused by the actual rolling of uranium metal. However, after the salt bath furnace was utilized, airborne contamination from the rolling operations was greatly decreased. The median value of all the air samples collected in this period is slightly less than 0.2 MAC which raises the concern regarding previously minor sources of airborne contamination. These other sources would have to be distant from the rolling operations; otherwise airborne contamination would be measured, at least partially, on the air samples taken near the rolling operations.

Grinding of the uranium billets to remove surface imperfections was a documented operation at Bethlehem Steel for some of the rollings. A single process air sample was obtained for this operation. The air sample (70 MAC) was actually the highest recorded at Bethlehem Steel during the later time frame. This value was used to estimate the air concentrations for the later period at Bethlehem Steel. As with previous periods, it is assumed that the operators inhaled this concentration continuously for a 10 hour work day on which uranium rolling occurred. Based on measurements conducted at the

Joslyn Steel plant taken while grinding on uranium metal (both breathing zone and general air samples), air concentration ranged from 0.4 MAC to 17 MAC. Harris indicated that portable grinding operations result in an average daily concentration of 5.7 MAC. This indicates the 70 MAC concentration determined from a process sample provides an upper bound to the operation.

While there may have been other sources of airborne contamination, however, it is likely that this estimate is a bounding estimate except for an exposure category of workers (cobble cutters) discussed below. For other sources to be bounding, they would have to produce greater than 700 MAC-hours of exposure per day (70 MAC times 10 hours per day). This would require any other operation to not only create higher air concentrations, but to do so routinely. The most likely routine source of elevated airborne activity that has been postulated at Bethlehem Steel is the cutting of cobbles (Transcript November 28, 2005).

3.4.5 Determination of intakes to cobble cutters (1949 - 1952)

NIOSH has determined, and the Secretary, Health and Human Services has concurred, that it is not feasible to reconstruct internal radiation from exposures to uranium radionuclides for all Atomic Weapons Employer employees who worked at Bethlehem Steel Corporation from January 1, 1949 – December 31, 1950. For the period 1951-1952, NIOSH has determined, and the Secretary, Health and Human Services has concurred, that it is not feasible to reconstruct internal radiation doses from internal exposures to uranium radionuclides for Bethlehem Steel Corporation cobble cutting activities.

3.5 Evaluation of ingestion dose

Ingestion intakes can be most closely related to surface contamination values. Very few measurements exist for surface contamination. However, airborne contamination levels and surface contamination levels are generally related. To evaluate the relationship between air contamination and surface contamination, NIOSH reviewed the available air and surface contamination measurements at Simonds Saw and Steel and Bethlehem Steel. At Simonds Saw Steel these measurements were taken during a uranium rolling campaign on 10/27/48, while at Bethlehem Steel data were available for a rolling on 9/14/1952. The Bethlehem Steel surface contamination data were obtained by smears wiped over a 100 cm^2 area. As such, they represent only the removable portion of the contamination. The Simonds Saw surface contamination data were direct measurements that were made with a portable instrument called a Zeuto. This type of instrument has an active surface area that is 3 inches by 4 inches or approximately 75 cm^2.

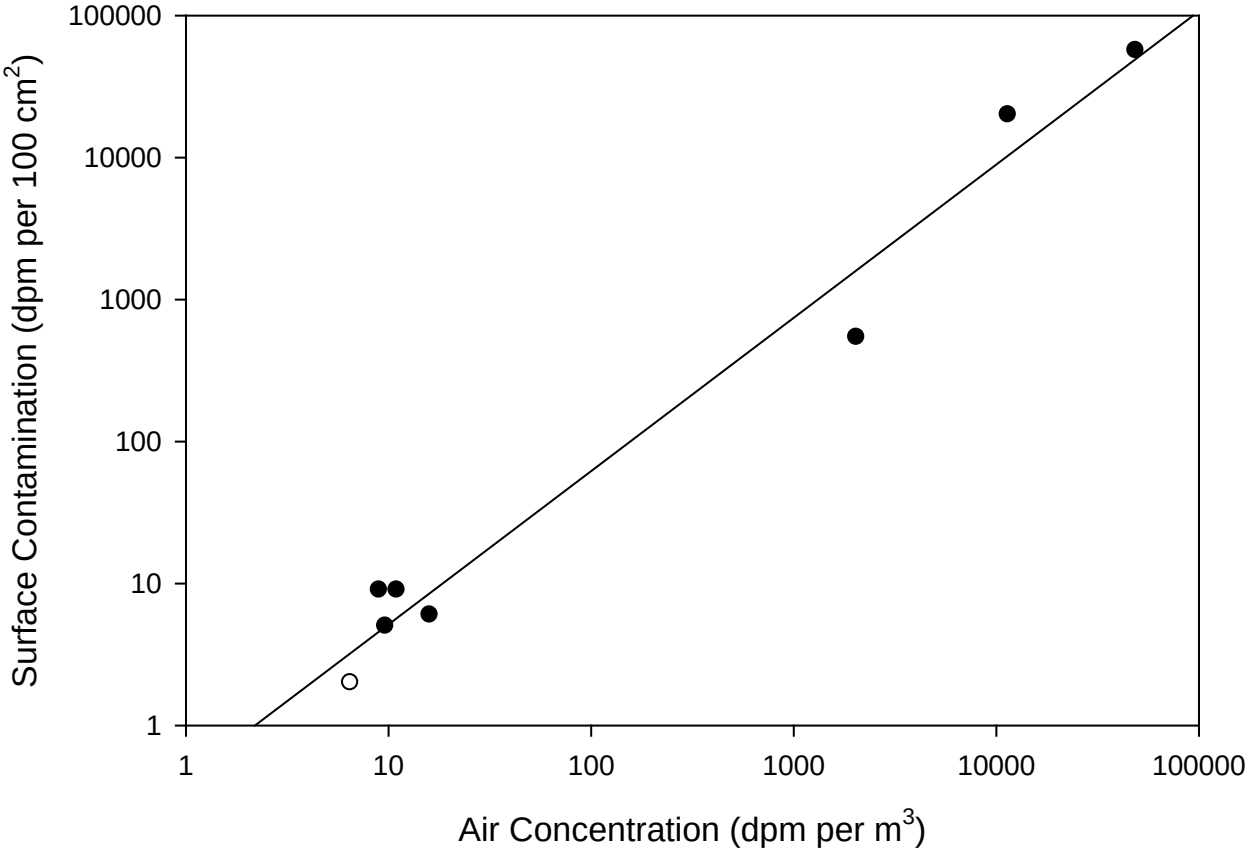
Each rolling stand at both Bethlehem Steel and Simonds Saw was evaluated along with the shear at Bethlehem Steel. Stand #6 at Bethlehem Steel was not evaluated because the surface smear indicated no detectable activity. Where more than one sample was taken, the results were averaged. Table 2 shows the average air and surface contamination measurements for these locations. The surface contamination measurements at Simonds Saw were normalized to 100 cm^2.

The values for each point are plotted in Figure 6. A clear trend can be seen in the graph, which indicates that the surface contamination is proportional to the air contamination. It is also worthy of note that this relationship is internally consistent at the two facilities. That is, high airborne activity is predictive of high surface contamination levels and vice versa. This means that if any large particle surface contamination that does not add to the air concentrations exists, the fraction of surface contamination represented by this is consistent across locations and sites and concentrations. Using this relationship, a model was developed that relates the ingestion rate to air concentrations.

Table 2: Air and Surface Contamination Values

Air sample #	Air concentration (dpm/m^3)	Surf. Contamination location	Surf. Contamination value (dpm/100 cm^2)
Simonds Saw Data			
L709	49000		
L710	75000	east roller 1	50000
L711	22400	west roller 1	35000
Average	48800	Average	42500
L718	14800		
L719	23800		
L720	27900		
L721	943		
L722	836		
L723	418	west roller 2	15000
average	11449.5	Average	15000
Bethlehem Steel Data			
Q921	2076		
Q922	2973	Shear	679
Q923	1080	Shear	404
Average	2043	Average	541.5
Q903	3		
Q905	10	Stand 1	2
Average	6.5	Average	2
Q906	10		
Q908	12	Stand 2	9
Average	11	Average	9
Q909	18		
Q911	14	Stand 3	6
Average	16	Average	6
Q912	13		
Q913	10		
Q920	6	Stand 4	5
Average	9.7	Average	5
Q914	12		
Q915	3		
Q919	12	Stand 5	9
Average	9	Average	9

Figure 6: Graph of observed air concentration and surface contamination levels at Simonds Saw and Bethlehem Steel.



The computer program RESRAD-BUILD contains a model for estimating ingestion intakes from surface contamination levels. The model contains a parameter for the ingestion rate that is expressed in units of m^2/hr, which expresses the amount of contamination ingested as a portion of the contamination contained in an effective area. This is intended to be a multiplier for removable surface contamination which can be used to arrive at an hourly ingestion rate. The default distribution used by RESRAD is a loguniform distribution between 2.8×10^{-5} and 2.9×10^{-4} m^2/hr with a mean of 1.1×10^{-4} m^2/hr. This distribution is provided in NUREG/CR-5512 volume 1, while the development of this parameter is discussed in volume 3 of the same NUREG.

Table 3 lists the average air concentrations and the average surface contamination levels (expressed in dpm/m^2) measured at Simonds Saw and Bethlehem Steel. It also lists the estimated hourly inhalation and ingestion rates inferred from these data. The hourly inhalation rate is based on the assumed 1.7 m^3/hr breathing rate. The hourly ingestion rate is based on the upper bound of the distribution provided in NUREG/CR-5512 of 2.9×10^{-4} m^2/hr. The table also included the calculated ingestion rate as a fraction of the inhalation rate. This is simply the calculated ingestion rate divided by the calculated inhalation rate.

Table 3: Calculated Inhalation and Ingestion Rates

Air Concentration (dpm/ m^3)	Surface Contamination (dpm/ m^2)	Hourly inhalation rate (dpm/hr)	Hourly ingestion rate (dpm/hr)	Fractional ingestion rate
48800	5666667	82960	1643.33	0.019809
11449.5	2000000	19464.15	580	0.029798
2043	54150	3473.1	15.70	0.004521
6.5	200	11.05	0.06	0.005249
11	900	18.7	0.26	0.013957
16	600	27.2	0.17	0.006397
9	900	15.3	0.26	0.017059
9.7	500	16.43	0.15	0.008824
			Average	0.013202

Ingestion intakes at Bethlehem Steel will use the highest of these fractional rates (0.0298). This rate will be multiplied by the applicable inhalation rate to obtain the ingestion rate. In this way, the ingestion rate will change as the estimated conditions at the facility change.

3.6 Evaluation of inhalation and ingestion due to residual contamination

Residual contamination of the facility following rolling operations would have been present in the form of uranium oxide dust on the floor and other horizontal surfaces. No surface or airborne contamination surveys could be found from Bethlehem Steel during days in which only steel was processed. However, it was noted that uranium rolling occurred primarily on weekends because the 10" continuous bar mill was being fully utilized for steel production during the week.

The principal product of the continuous rolling mill at Bethlehem Steel, measured in thousands of tons per year, was steel. On days in which Bethlehem Steel was not rolling uranium, steel was being produced. The production of steel generates large quantities of dust and debris. As steel is rolled, a coating of this dust is likely to settle on top of any uranium contamination. This would act as a protective layer making it less likely that the uranium would be resuspended. However, it is possible that as uranium contamination is resuspended in the air, it settles back to horizontal surfaces and essentially forms a mixture of uranium and steel. This would allow uranium to continue to be resuspended but only as part of a mixture. The resuspension of material requires some mode of force, such as ventilation, foot or vehicular traffic, etc. It is likely the same type of forces exist whether the mill was rolling steel or uranium. It is therefore, likely that the same mass of material is resuspended at any one time. As the steel debris builds up, this resuspended material is composed of fractionally less uranium and more steel.

The dose from residual contamination was determined based on the above concepts which result in the resuspension of contamination. The uranium contamination was assumed to be diluted by additional rollings of steel in between uranium rollings. For the purposes of this model, it has been assumed that an equal mass of steel is added to the uranium each day. This is a conservative estimate because the steel production was measured in thousands of tons per year while uranium was rolled only on a limited basis (on the order of a few hundred tons). The material available for resuspension one day after a uranium rolling would therefore be one part uranium and one part steel. On the following day, the material would be one part uranium and two parts steel and so on.

While rolling operations could result in high localized air concentrations, air concentrations from resuspension of residual contamination would be more consistent throughout the area. Therefore, the median general air concentrations are used as the starting point. This value is then assumed to decrease in the days following uranium rolling as described above. The average air concentration due to resuspension of residual contamination can be estimated by the following expression.

$$C_{Avg} = C_{Int.} * \frac{\int_{1}^{30} dt/t}{29} = C_{Int.} * \frac{\ln(t)_1^{30}}{29} = C_{Int.} * 0.117$$

Where:

$C_{Avg.}$ = the average air concentration through the 29 days following a rolling

$C_{Int.}$ = the median general air concentration on the day of rolling

t = the number of days following the day of rolling

The median general area air sample concentrations for the two time periods are listed in table 4.

Table 4: Median General Area Air Sample Concentrations

	Median general area air samples (MAC)
Bethlehem Steel (early)	0.215
Bethlehem Steel (late)	0.081

The same method was used for ingestion, however, the initial concentration was replaced by the daily ingestion rate on rolling days.

3.7 Summary of internal dose guidance for Bethlehem Steel

The following tables summarize the data from the previous sections for the purpose of conducting internal dose estimates at Bethlehem Steel. The rolling data and residual contamination has been averaged over the applicable time frame to determine an intake rate per calendar day. These values should then be applied as a continuous chronic intake to determine dose. While the typical rolling schedule was one per month, several months do not follow this rule. However, for ease of calculation, residual periods were assumed to be 20 work days per rolling. Also, exposures shall be determined as full month time frames for any partial month worked to account for the slightly non-uniform rollings schedule (e.g., if a worker was employed for part of a month, use the entire month).

Table 5: Summary of exposure values during rolling days

Time Period	Air concentration on rolling days	Time (hours/day)	Breathing rate (m^3/hr)	Inhalation during rolling days (dpm/day)	Average inhalation rate on non-rolling (dpm/day)	Ingestion during rolling days (dpm)	Average ingestion rate on non-rolling work days (dpm/day)
1/1/1951 – 9/30/1951	225 MAC	10	1.7	267,750	30	7,979	1,173
10/1/1951 – 12/31/1952	70 MAC	10	1.7	83,300	11.3	2,482	365

Table 6: Summary of inhalation exposure values for the periods 1951-1952 at Bethlehem Steel

Time Period	Number of rollings	Total inhalation from rolling day exposure (dpm)	Total Inhalation from residual contamination (dpm)	Total Inhalation during period (dpm)	Total Inhalation rate (dpm/ calendar day)
1/1/1951 – 9/30/1951	10	2,677,500	5,400	2,682,900	9,864
10/1/1951 – 12/31/1952	18	1,499,400	3,378	1,502,778	3,288

Table 7: Summary of ingestion exposure values for the periods 1951-1952 at Bethlehem Steel for all workers

Time Period	Number of rollings	Total ingestion during rollings (dpm)	Total ingestion during from residual contamination (dpm)	Total ingestion rate (dpm/ calendar day)
1/1/1951 – 9/30/1951	10	79,790	234,581	1,156
10/1/1951 – 12/31/1952	18	44,682	131,365	385

4.0 ESTIMATION OF EXTERNAL EXPOSURE

NIOSH has determined, and the Secretary, Health and Human Services has concurred, that it is not feasible to reconstruct external radiation doses from exposures to uranium radionuclides for all Atomic Weapons Employer employees who worked at Bethlehem Steel Corporation prior to 1951. Although NIOSH has found that it is not possible to completely reconstruct radiation doses for the proposed class, NIOSH intends to use any external monitoring data that may become available for an individual claim and that can be interpreted using existing NIOSH dose reconstruction processes or procedures. Therefore, dose reconstructions for individuals employed at Bethlehem Steel Corporation during the period January 1, 1949 through December 31, 1952, but who do not qualify for inclusion in the SEC may be performed using these data as appropriate.

No external dosimetry data is available for Bethlehem Steel. However, dose rates from submersion in a cloud of dust, direct exposure to uranium metal, and exposure to workers from skin contamination and reuse of their clothing are estimated below using the rolling information, residual contamination, and exposure rate constants for uranium materials.

4.1 Evaluation of external dose from uranium dust

Air concentrations derived in this document were combined with rolling times, number of rollings and the Dose Conversion Factors for ^{238}U and the daughter radionuclides ^{234}Th and ^{234m}Pa from Federal Guidance Report No. 12 (EPA 1993) to determine the external dose due to submersion in a natural uranium dust cloud. Only the skin is reported in Table 8 because all other doses were less than 1 mrem. The maximum annual dose to the skin listed in Table 8 is applied to electron (E > 15 keV) annual dose in IREP using a constant distribution and assuming a chronic exposure.

Table 8: Annual external dose due to submersion in air contaminated with natural uranium dust.

Time Frame	Annual Skin Dose* (Rem)
1951	0.001
1952	0.000

* Dose values are rounded to nearest mrem

4.2 Evaluation of external dose from direct contact with uranium billets

External doses from exposure to a uranium source were evaluated using an extended (semi-infinite plane) natural uranium source. Estimated surface dose rates of 230 mrad/hr at a depth of 7 mg/cm^2 and 2 mrad/hr at a depth of 1000 mg/cm^2 were obtained from a search of the literature (Coleman, Hudson, and Plato 1983; U.S. Army 1989). Conservative values for the time workers were located relative to the source were based on descriptions of processes and different job types (AEC 1948b). A triangular distribution for electron exposure from uranium was determined in the following manner:

- The minimum was estimated by assuming the worker was 1 meter from an extended uranium source for 1 hour (per 10-hour shift). The estimated dose rate for this scenario was 90 mrad/hr (US Army 1989).

- Survey data of the Simonds facility were used to estimate the mode. The highest value measured during those surveys was 15 mrad/hr (AEC 1949b). To be claimant-favorable, this dose rate was assumed for an entire 10-hour shift.

- A maximum value was estimated by assuming the worker was 0.3 meter (1 foot) from an extended uranium source for 6 hours (150 mrad/hr) and 1 meter away for 4 hours (90 mrad/hr).

Table 9 summarizes annual values for estimated external shallow dose due to electron exposure from uranium. The target organs for this type of exposure are the skin, male genitals, and breast. In the case of cancer of the male genitals or female breast cancer, additional evaluation might be needed to consider shielding and attenuation provided by clothing.

Table 9: Estimated external shallow dose due to electron exposure from natural uranium source.

Time Frame	Annual Organ Dose (Rem)		
	Min.	Mode	Max.
1951	1.17	1.95	16.38
1952	1.35	2.25	18.90

The values in Table 9 are entered in IREP as the annual dose due to electrons (E > 15 keV) using a triangular distribution and assuming a chronic exposure for cases where the target organ is the skin, male genitals, or breast.

The deep dose rate due to photon exposure (dose rate at 1,000 mg/cm^2) from natural uranium was estimated to be 2 mrad/hr (U.S. Army 1989). The estimated 2-mrad/hr deep dose rate from the uranium source is evenly divided between photons with energies E = 30-250 keV and E > 250 keV. Dose conversion factors DCF_{min}, DCF_{max}, and DCF_{AP}, for 30-250 keV photons (NIOSH 2002) were used to calculate the doses listed in Table 10. Dose conversion factors DCF_{min}, DCF_{max}, and DCF_{AP}, for E > 250 keV photons were used to calculate the doses in Table 11. The values in Table 12 and Table 11 are entered into IREP as organ doses due to the appropriate energy photons, using a triangular distribution and assuming a chronic exposure.

Table 10: Annual organ doses due to photons (30-250 keV) from natural uranium source for best estimate.

Organ	Annual organ dose (rem)					
	1951			1952		
	Min	Mode	Max	Min	Mode	Max
Bladder	0.005	0.122	0.131	0.005	0.122	0.131
Red bone marrow	0.008	0.062	0.109	0.008	0.062	0.109
Bone surface	0.050	0.119	0.197	0.050	0.119	0.197
Breast	0.006	0.165	0.193	0.006	0.165	0.193
Colon	0.007	0.104	0.112	0.007	0.104	0.112
Esophagus	0.004	0.068	0.095	0.004	0.068	0.095
Eye	0.000	0.123	0.141	0.000	0.123	0.141
Ovaries	0.004	0.094	0.103	0.004	0.094	0.103
Testes	0.005	0.142	0.148	0.005	0.142	0.148
Liver	0.013	0.105	0.111	0.013	0.105	0.111
Lung	0.017	0.097	0.112	0.017	0.097	0.112
Remainder organs	0.012	0.087	0.094	0.012	0.087	0.094
Skin	0.058	0.088	0.097	0.058	0.088	0.097
Stomach	0.006	0.124	0.132	0.006	0.124	0.132
Thymus	0.001	0.138	0.147	0.001	0.138	0.147
Thyroid	0.001	0.142	0.148	0.001	0.142	0.148
Uterus	0.006	0.099	0.108	0.006	0.099	0.108

Table 11: Annual organ doses due to photons (>250 keV) from natural uranium source for best estimate.

Organ	Annual organ dose (rem)					
	1951			1952		
	Min	Mode	Max	Min	Mode	Max
Bladder	0.059	0.118	0.123	0.059	0.118	0.123
Red bone marrow	0.065	0.097	0.119	0.065	0.097	0.119
Bone surface	0.073	0.103	0.116	0.073	0.103	0.116
Breast	0.072	0.121	0.147	0.072	0.121	0.147
Colon	0.058	0.113	0.116	0.058	0.113	0.116
Esophagus	0.059	0.100	0.114	0.059	0.100	0.114
Eye	0.027	0.118	0.127	0.027	0.118	0.127
Ovaries	0.056	0.110	0.125	0.056	0.110	0.125
Testes	0.063	0.127	0.137	0.063	0.127	0.137
Liver	0.063	0.115	0.117	0.063	0.115	0.117
Lung	0.069	0.113	0.119	0.069	0.113	0.119
Remainder organs	0.063	0.106	0.112	0.063	0.106	0.112
Skin	0.081	0.112	0.117	0.081	0.112	0.117
Stomach	0.063	0.119	0.125	0.063	0.119	0.125
Thymus	0.047	0.120	0.137	0.047	0.120	0.137
Thyroid	0.053	0.131	0.142	0.053	0.131	0.142
Uterus	0.055	0.105	0.106	0.055	0.105	0.106

4.3 Evaluation of external dose from residual contamination

The purpose of this section is to provide guidance for the evaluation of external dose from residual contamination and also dose associated with the reuse of personal clothing between rollings.

An estimate of surface contamination was calculated by using the terminal settling velocity of 0.00075 m s^{-1} (TIB-0004, rev 2) multiplied by the rolling day concentrations and by the amount of time uranium was rolled in one year. The Simonds Saw and Steel concentration data was used for all years to simplify the calculations as it overestimates the later rolling data. This results in contamination of 12,500,000 dpm m^{-2} (1,250,000 dpm 100 cm^{-2}) which exceeds all the measured surface contamination levels. This value was then assumed to be constant through all years of rolling. The residual contamination value was converted to dose using the dose coefficients for contaminated ground surfaces for U-238 and progeny Pa-234m and Th-234 from Federal Guidance Report No. 12 (US EPA 1993). The doses from contaminated sources are in the following table. Doses were only listed for Skin, Bone Surfaces, and all other organs. The all other organ category is the highest other organ rounded up to the nearest mrem. The doses in Table 12 shall be entered into IREP assuming a photon energy range of 50% 30-250 keV and 50% >250 keV.

Table 12: Annual dose from contaminated surfaces at Bethlehem Steel, 1951 to 1952.

Time Frame	Skin (rem)	Bone Surfaces (rem)	All other organs (rem)
All years	1.771	0.010	0.005

The use of contaminated clothing following the rolling of uranium as discussed in worker interviews has been given careful consideration. Average dose data from contaminated clothing at Mallinckrodt indicate levels of 1.5 mrem/hour (AEC 1958). Bethlehem Steel doses were estimated using this as a bounding condition based on the types of materials handled and quantity of materials handled at Mallinckrodt. The dose rate was determined assuming the clothing was worn for two work weeks prior to cleaning. Therefore, the annual dose to the skin is determined by assuming 1.5 mrem/hour times 50 hours per week times 2 weeks per month times 12 months per year. This results in an annual dose to the skin of 1.8 rem per year which will be assigned a constant dose rate from electrons with an energy > 15 keV.

5.0 OCCUPATIONAL MEDICAL DOSE

This TBD assumes that all workers received an annual occupationally related diagnostic chest X-ray (Simonds 1948). The exposure geometry was assumed to be posterior-anterior (PA) (NIOSH 2002). Annual X-ray data from OTIB-0006, “Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures” and associated instructions shall be used for the purposes of evaluating occupational medical dose at Bethlehem Steel.

6.0 OCCUPATIONAL ENVIRONMENTAL DOSE

Occupational environmental dose provides a mechanism to account for dose that has not been monitored or attributed to occupational exposure. The exposures of all employees of the Bethlehem Steel Corporation at the Lackawanna plant will be estimated based on the 95% air concentration at the rolling mill for a 10 hour day. This estimate precludes the use of environmental dose which would be much lower than the exposures estimated. As such, no environmental dose shall be assigned to the workers at this facility.

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